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Quantitative Electroencephalography Patterns Associated With Medical Conditions

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This article summarizes some of the quantitative electroencephalography EEG (QEEG) and QEEG literature associated with several medical conditions. This peer-reviewed scientific literature demonstrates that we can commonly expect to find disturbed electrophysiological patterns associated with Lyme disease, systemic lupus erythematosus, migraines, irritable bowel syndrome, and cardiopulmonary bypass surgery patients. Abnormal EEG patterns are also commonly found in fibromyalgia and chronic fatigue and in individuals with chemical sensitivities and those who have been exposed to toxic substances or extensive radiation. This literature encourages us that EEG biofeedback holds potential to assist patients with all of these conditions, and the data provided have implications for how neurofeedback treatment may be done.

Introduction

Through the years, there has been a tremendous amount of electroencephalography (EEG) and quantitative EEG (QEEG) research documenting abnormal brain wave patterns associated with various medical conditions. This extensive literature is beyond the limits of what can be reviewed in this venue. However, in the remainder of this article, I will endeavor to provide an overview of some of this literature, also occasionally citing neuroimaging studies, even though it will be less than fully comprehensive. It is hoped that this may be informative for therapists using neurofeedback to work with these conditions.

Anticipating that some readers may be less than fully conversant with the definitions of some commonly used QEEG terminology, I will begin by defining a couple of terms. *Absolute power* refers to the amount of energy within the delta, theta, alpha, and beta frequency bands. *Amplitude* is the voltage of the EEG signal's waveform from the top (negative) to bottom (positive) side of the waveform (referred to as peak to peak). *Magnitude* is the average amplitude within the EEG sample, and absolute power is the square of magnitude. In contrast, the term *relative power* refers to a measurement of the percentage or proportion of total power within each frequency band. Thus, a change in one narrow frequency band can alter the entire spectrum of relative power measures. In comparison, the fast fourier transform (FFT) is independently computed in absolute power in each frequency band or bin, so that an increase in one frequency or one hertz bin does not have any effect on any other frequency. In contrast, in relative power, an increase in one frequency band such as beta may simply be due to a decrease in another frequency band such as theta, which has nothing to do with beta. Thus, we tend to rely more heavily on absolute power measures rather than relative power in making neurofeedback recommendations.

Lyme Disease

Chabot and Sigal (1995) evaluated 29 patients with Lyme disease. Abnormal QEEG or evoked potentials were found in 75% of active Lyme disease patients, and "despite treatment, persisting signs of cortical neurophysiological dysfunction were still present in 54% of the patients in the post CNS [central nervous system] Lyme disease group" (p. 143). Some patients manifested excess theta and/or delta power, similar to dementia and systemic lupus with cognitive complaints. The major complaint of this subgroup was memory problems. Two patients, on the other hand, displayed cortical hyperexcitability, with excess absolute and relative power beta in one case (who complained of anxiety, headaches, and sleep problems) and excess alpha with increased alpha mean frequency in the other case (who complained of fatigue and sleep problems). Several patients also displayed focal abnormalities involving left/right hemisphere power asymmetry and/or incoherence problems.

Systemic Lupus Erythematosus (SLE)

Ritchlin et al. (1992) evaluated SLE patients with and without neuropsychiatric symptoms. As might be anticipated from the research that has been done with dementia, those SLE patients with dementia had patterns of

excess theta absolute and relative power. Patients with delirium displayed an excess of delta and theta absolute and relative power, a deficit of alpha relative power, and a beta absolute power excess. Depressed SLE patients displayed excess beta and deficient delta absolute and relative power.

In SLE patients manifesting more mild neuropsychiatric symptoms, cognitive symptoms were associated with excess theta absolute and relative power and a deficit of delta and beta relative power. Those with affective symptoms displayed excess beta relative and absolute power, as well as excess theta and alpha absolute power. In this group, patients with neurological symptoms evidenced excess beta relative and absolute power, excess theta absolute power, and elevated theta relative power.

In a study of neuropsychiatric lupus (NP-SLE) patients with less obvious psychiatric disturbances, Nobili et al. (1996) found a reduction in alpha relative power in posterior and anterior regions, an increase in theta relative power, and an increase in delta power occipitally in florid NP-SLE patients compared with normal control participants. In patients with previous NP-SLE, there was a significant reduction of alpha relative power in posterior and central regions, an increase in both delta and theta relative power occipitally, and a slight decrease in absolute alpha power posteriorly. *Sensitivity* in diagnostic QEEG literature refers to persons with a disorder being correctly predicted or classified in a statistically significant way on the basis of their QEEG patterns. Whereas Ritchlin et al. (1992) reported an overall sensitivity of 80%, with a weaker prevalence of psychiatric disturbances, Nobili et al. (1996) reported a sensitivity of only 59% (with florid NP-SLE patients) and 44% (with previous NP-SLE), whereas regional cerebral blood flow performed better, producing sensitivities of 76% and 78%. Regional cerebral blood flow was found to be consistent with clinical course in 90% of cases, whereas QEEG was consistent in 60% of cases.

Headache and Migraine

Gerez-Malo and Tello-Valdes (1996) reported that chronic migraine is associated with decreased delta power. One group (Valdizan, Andreu, Almarcegui, & Olivito, 1994) studied children with tension headaches and migraines with and without auras in comparison to a normal control group. In children with migraines with aura, who were evaluated during a headache-free period, the researchers found slowing with increased theta (increase in the theta/alpha ratio) in posterior (occipital and temporal) regions. This confirmed Hughes and Robbins's (1990) finding of increased theta at O_1 and of alpha at O_1 and T_6 in 82% of their patients. Almarcegui, Andreu, Olivito, and Validzan (1994) similarly reported that in patients with migraine with aura, there was an increase in the theta/alpha ratio in posterior and occipital regions. Likewise, Genco, de Tommasco, Prudenzano, Savarese, and Puca (1994) determined that during headache-free periods, children with migraines had a significant increase in theta relative power and an alpha interhemispheric asymmetry (in those both with and without aura). Genco et al. (1994) further found that in adults, there was an increase of slow delta and interhemispheric alpha asymmetry, confirming previous research (Donati et al., 1990; Nycke, Kangasniemi, & Lang, 1990; Pacchetti et al., 1990; Seri, Cerquilini, & Guidetti, 1993). In addition to the alpha asymmetry in posterior areas in migraine with aura, Donati et al. (1990) also found increased slow activity (theta and delta), particularly temporally. Pothmann (1993) likewise identified a parietal alpha power asymmetry in 44% of children during a migraine but in only 25% of those with tension headaches, confirming Schoenen, Jamart, and Dewalde's (1987a, 1987b) research.

In studying migraine without aura, Schoenen et al. (1987a) found that there was a unilateral disturbance early in a migraine and persisting throughout—a reduction of alpha and theta over one occipital area, usually on the side of the headache. In 19 of 22 patients studied during an attack of common migraine, the only abnormality was markedly reduced alpha activity over one occipital region, usually on the side of the headache. Sixteen of these 22 patients had concomitant reduction of theta activity in the same location. In all patients except one, restudied at least 7 days after an attack, EEG asymmetries had disappeared. Thus, clinicians should be alert to the fact that it appears that a posterior asymmetry is frequently present, sometimes during migraine and sometimes in headache-free periods. Overall, it appears that migraine with aura may often increase slower wave activity in occipital-temporal areas, often with a posterior alpha asymmetry.

EEGs during basilar migraine attacks in children also show posterior slow activity (delta and theta), perhaps due to ischemia in posterior cerebral arteries (Beaumanoir & Jekiel, 1987; Bouquet & Cernibori, 1981; Ceribori & Bouquet, 1984; DeRomanis, Buzzi, Assenza, Brusa, & Cerbo, 1993; Eviatar, 1981; Gascon & Barlow, 1970; Guidetti, Seri, Cerquilini, & Brinciotti, 1989; Lapkin & Golden, 1978). Seri et al. (1993) also noted that an increase

in frontal delta activity, along with occipital alpha suppression, occurs during migraine with visual aura. Other results (Ramelli, Sturzenegger, Donati, & Karbowski, 1998) suggested that the EEG may change during the course of a basilar migraine, within 4 hours of onset, polymorphic delta activity predominated, whereas 16 hours after migraine onset, increased delta-theta activity has been found to be predominant over the occipital regions.

One report (Simon, Zimmerman, Sanderson, & Tasman, 1983) suggested that driving from photic stimulation is enhanced in adults with a history of migraine, whereas children may not be as responsive to photic driving. This suggests that neurofeedback therapists who use simultaneous photic stimulation may find that this could add a useful component in working with adult migraine sufferers.

Irritable Bowel Syndrome (IBS)

IBS is a functional bowel disorder associated with symptoms of abdominal bloating and pain, diarrhea, constipation, and compromised quality of life. In a study comparing 24 IBS patients with controls, Nomura, Fukudo, Matsuoka, and Hongo (1999) concluded that "IBS patients consistently showed a decrease of alpha power percentage and an increase of beta power percentage not only in the conscious relaxed state but also during the stress of cholinergic-stimulated conditions. This suggests that such an altered brain activity is a trait of IBS patient" (p. 483). They found a significant positive correlation between the colonic motility index and beta power percentage. Their findings replicated a previous study by Fukudo, Nomura, Muranaka, and Taguchi (1993). This excess beta and the fact that most IBS patients complain of stress-induced exacerbation of symptoms help explain why as little as four to six sessions of self-hypnosis training has proven effective in producing significant improvement in more than 80% of IBS patients (Tan & Hammond, 2005).

Cardiopulmonary Bypass Surgery Patients

Gugino et al. (1997) performed neuropsychological testing and QEEG evaluations before and after bypass surgery. Before surgery, 39.5% of patients showed deficits on neuropsychological testing and 39.5% had abnormal QEEGs. Thus, about 40% of bypass surgery patients have compromised cortical function prior to surgery. The patterns of abnormality were most often a slowing of the EEG with excess theta relative and/or absolute power, frequency slowing (decreased delta and beta absolute power), and a dramatic decrease in alpha mean frequency. One week after surgery, 40.6% of the patients were found to have developed a new neuropsychological deficit. The QEEGs on these individuals showed decreased interhemispheric coherence, elevated delta and decreased theta absolute power (particularly in posterior areas), greater posterior/anterior asymmetry, and increased delta mean frequency. In 86.7% of cases, the EEG abnormalities were generalized and demonstrated the kind of slowing seen with ischemic problems (Jonkman, Poortvliet, Veering, deWeerd, & John, 1985) or in early stages of Alzheimer's disease. In relation to this, short-term memory problems were a frequent complaint. There was a 93.3% concordance between the QEEG evaluation and neuropsychological testing. On the positive side for these patients, 3 months after surgery, cognitive deficits on neuropsychological testing had decreased from 40.6% to 28.1%. Thus, cognitive function was being recovered.

Chronic Fatigue Syndrome (CFS) and Fibromyalgia

There are only minimal EEG data available on CFS and fibromyalgia. Therefore, prior to reviewing it, I will cite presumptive evidence of brain dysfunction in these conditions. DeLuca, Johnson, Ellis, and Natelson (1997b) found that CFS patients who have a gradual onset of the illness tend to be more likely to have a comorbid psychiatric diagnosis, a finding supported by research by Mawle, Steele, Reyes, Dobbins, and Reeves (1994), who found that CFS patients with a gradual onset had significantly more major life events occurring in the year prior to onset compared to CFS patients with a rapid onset. Similarly, patients with multiple chemical sensitivities who do not have a clear date of onset are more likely to have a psychiatric diagnosis (62%) than are those with an identifiable onset (26%; Fiedler, Kipen, DeLuca, Kelly-McNeil, & Natelson, 1996). The Johnson and DeLuca group (DeLuca et al., 1997b) seems to believe that patients with a more rapid onset of symptoms are more likely to be associated with a disease entity, such as a virus (e.g., Epstein-Barr virus, enteroviruses, a putative human T lymphotropic virus type III), that may eventually be isolated.

Some studies have suggested that an encephalitic process may be involved with CFS (Buchwald et al., 1992; Ichese et al., 1992; Natelson, Cohen, Brassloff, & Lee, 1993; Schwartz et al., 1994). For example, Schwartz et al. (1994) found that CFS patients had significantly more defects (81%) throughout the cortex on single-

photo emission computed tomography scans than did normal subjects (21%). The most common sites of defects in CFS patients, and the only ones that were significantly different from normal control subjects, were in the lateral frontal cortex, lateral temporal cortex, and basal ganglia. The CFS patients had more than 10 times the number of defects compared with control subjects. These authors concluded that complaints of afflicted patients, particularly those involving the CNS, can be misdiagnosed or even considered by some to be factitious. The finding of abnormal neuroimaging studies in the vast majority (94%) of patients with CFS indicates, however, that this condition is associated with physiologic changes that can be observed objectively. (p. 939)

The authors state that CFS may be due to a virus or to vascular problems. The frontal and temporal lobes were also implicated by Ichese et al. (1992) and Goldstein, Mena, Jouanne, and Lesser (1995). Ray, Phillips, and Weir (1993) found hypoperfusion in the basal ganglia, and Costa, Brostoff, Douli, and Ell (1992) and Costa, Tannock, and Brostoff (1995) in the brain stem.

Unpublished QEEG data from Duffy's (1999) CFS patients shows that many of them have high-amplitude sharp EEG alpha, scattered sharp waves, and a lack of any tendency to fall asleep—unusual in a syndrome associated with fatigue. Duffy expressed the belief that "CFS appears to involve the brain and result in changes in its electrical activity….The fact that qEEG findings were reasonably consistent across most CFS patients suggests that brain involvement may be much more common than thought." In 28 females with CFS, Billiot, Budzynski, and Andrasik (1997) also found increased 5- to 7-Hz theta at Cz compared to age-matched controls.

DeLuca et al. (1997a, 1997b) have found that patients with a sudden onset of CFS experience more difficulties with cognitive impairment (e.g., verbal memory, attention, and information processing) than do patients with a gradual onset, CFS patients with psychiatric comorbidity, and controls. The findings by DeLuca et al. (1997a, 1997b) have important implications for treatment. CFS patients with gradual onset and a psychiatric history may well benefit more from psychotherapeutic and psychotropic medication management. On the other hand, patients with a more rapid onset and without a history of psychiatric comorbidity may benefit more from education about symptom management, being assessed with QEEG, and from undergoing neurofeedback. The latter finding is supported not only by the neuroimaging research cited above but also by another recent study by the DeLuca group.

Lange et al. (1999) used magnetic resonance imaging to examine CFS patients with and without psychiatric comorbidities. The noncomorbidity CFS group showed a significantly larger number of brain abnormalities on T2-weighted images than the CFS group with psychiatric diagnosis since disease onset and than healthy sedentary controls. The cerebral abnormalities of the CFS, nonpsychiatric group consisted mostly of frontal lobe problems consisting of small, punctate, subcortical white matter hyperintensities. This finding could explain the more severe cognitive impairments that the Lange et al. group previously found in more rapid onset CFS cases without a psychiatric history.

Fibromyalgia is another syndrome like CFS but with the addition that patients experience widespread soft tissue pain, including headaches and temporomandibular joint (TM) pain. This condition is also typified by a decreased ability to concentrate, problems with short-term memory, and difficulty with multitasking. This is popularly referred to as fibro fog. Fibromyalgia may involve many etiologic factors (M. Donaldson, Donaldson, Mueller, & Sella, 2003; Esty, in press), and one study (Alexander et al., 1998) found that 57% of fibromyalgia patients had a history of sexual or physical abuse, which correlated with more severe fibromyalgia symptoms.

C. C. S. Donaldson, Sella, and Mueller (1998) evaluated dominant brain wave frequencies at 13 electrode sites in 157 fibromyalgia patients, but some of the patients remained on medications at the time of evaluation. They found considerable overlap between theta and alpha, with some dominant frequencies in the 6- to 10-Hz range. The dominant brain wave was in theta 28.1% of the time, in alpha 14.3% of the time, and in the theta/alpha range 17.3% of the time. When analyzed by site, slow wave frequencies were dominant at 8 of 13 sites, particularly in the frontal and central areas. In this condition that can overlap with so many other disorders, the authors believed that slow wave dominance was the most specific paradigm found to date in fibromyalgia.

The M. Donaldson, Donaldson, et al. (2003) article examined 40 fibromyalgia sufferers (who were able and willing to stop taking their medications) with QEEG, pain measures, and psychological testing. Interestingly, the QEEG did not differentiate fibromyalgia patients from the norm when analyzed as a whole, but when QEEG data were covaried with the Global Severity Index of the Symptom Checklist 90-R, the researchers found different patterns of relative power associated with three distinct groups. Excess theta activity was significantly (*p*

< .03) higher in the most severely distressed group, which also showed relatively little alpha activity. In contrast, the group with the least psychological distress and pain was found to have the greatest alpha power with relatively little theta relative power. Thus, slowing of the EEG from alpha to theta was associated with greater psychological distress and reduced cognitive efficiency. M. Donaldson, Donaldson, et al. concluded that the alpha/theta power balance reflected the level of psychological distress due to the pain being experienced, rather than the pain experience itself. Delta was low in all groups, perhaps associated with the problems of fibromyalgia patients with nonrestorative sleep.

One other EEG finding is relevant to fibromyalgia and neurofeedback work with this condition. The appearance of alpha activity has been found to predict which patients undergoing chemical-surgical anesthesia will remember events that occurred during surgery (Bennett, 1988; Mungali & Jones, 1994) because part of the brain remains in a scanning mode. Similarly, Perlis et al. (1997) found that alpha activity during sleep in fibromyalgia patients is associated with the nonrestorative sleep that they experience. Those fibromyalgia patients with more alpha activity showed an increased tendency to become aroused in response to background noises because of their shallow sleep. Therefore, if we reduce excess alpha with neurofeedback, it may lead to a deeper, restorative sleep.

Exposure to Neurotoxic Substances, Radiation, and Chemical Sensitivity

Cognitive impairments have been documented in individuals, such as miners, exposed to aluminum dust (Rifat, Eastwood, Crapper McLachlan, & Corney, 1990; White et al., 1992). Hanninen, Matikainen, Kovala, Valkonen, and Riihimaki (1994) found that welders with higher serum levels of aluminum had more slow-wave (delta and theta) activity and less alpha activity frontally than did welders with lower serum aluminum levels. Orbaek, Rosen, and Svensson (1988) found that workers exposed to solvents suffered from toxic encephalopathies, with increases in total power across multiple frequency bands.

Bell, Schwartz, Hardin, Baldwin, and Kline (1998) evaluated women who subjectively reported chemical intolerance compared with depressed woman and normal controls. Although 71% of the women with chemical intolerance had been diagnosed previously in their lives with depression, they exhibited a different QEEG pattern than the other groups did, with significantly more eyes-closed absolute alpha activity, particularly at Pz, and increased frontal alpha after sensitization. These findings, along with Marlowe-Crowne scores (measuring repression) that did not differ between groups, provided some indirect support for the view that chemical intolerance is not simply a misattributed psychiatric condition. These findings are also similar to those reported for workers exposed to styrene, who showed increases in absolute alpha (Matikainen, Forsman-Gronholm, Pfaffli, & Juntunen, 1993).

Zhavoronkova, Kholodova, Zubovsky, Gogiticize, and Koptelov (1995) evaluated 100 patients (compared to a control group) who were exposed to radiation during the cleanup of the Chernobyl disaster in 1986 to 1987. Seventy percent displayed paroxysmal activity and intermittent seizures. The paroxysmal activity consisted of synchronous discharges from both hemispheres, without spike components, which is regarded as coming from a deep level, perhaps diencephalic in origin. Source localization suggested the paroxysmal events came from deep structures near the midline. Autonomic disturbances in these patients included disruption of sleep cycles, emotional lability, memory changes, and headaches. QEEG findings demonstrated elevated alpha and theta power, particularly in frontal and central areas in one group, whereas others displayed lower alpha power. Whereas interhemispheric coherence in healthy subjects was highest in homologous frontal sites, in those exposed to radiation, it was lowest in the front and higher in central areas in almost all spectral bands. Intrahemispheric coherence was also decreased in the left hemisphere in patients and increased in the right hemisphere, which was exactly the opposite of healthy control subjects.

Conclusion

This brief review documents that abnormal electrophysiological patterns are commonly associated with many medical conditions. This implies that neurofeedback has the potential for improving the functioning of people with conditions such as fibromyalgia, IBS, migraine headaches, exposure to toxic agents, and so forth. We must bear in mind that in conditions such as Lyme disease, or whereever insidious viral agents continue to be influential, neurofeedback results may be only partially helpful and that improvements obtained through neurofeedback treatments may not be sustained without some degree of ongoing reinforcement. QEEG literature in general informs us that we can usually anticipate some heterogeneity in how the brain is functioning in patients within any broad diagnostic category. Thus, rather than simply providing protocol strategies, the information in

this review may be most helpful in providing comparative information for clinicians as they examine the results of their own EEG assessments before beginning treatment with patients with many of these conditions.

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